Spörel, Frank

Hydro-abrasive exposure and damage – appropriate concrete resistance

Workshop Proceedings

Hydro-abrasive exposure and damage – appropriate concrete resistance

Frank Spörel
Dipl.-Ing., Ph.D.
Federal Waterways Engineering and Research Institute (BAW)
Kussmaulstraße 17, GER-76187 Karlsruhe
e-mail: frank.spoerel@baw.de

ABSTRACT
In Germany currently about 10 percent of the weirs under the responsibility of the Federal Ministry of Transport and Digital Infrastructure reveal damages caused by hydro-abrasive exposure which impair the serviceability or load-bearing capacity. Unlike as for other exposure such as freeze-thaw attack there are no regulations in European standards which give requirements to assure a sufficient durability against hydro-abrasive exposure. For this reason the BAW has initiated a research project with the aim to classify the exposure of hydro-abrasive attack on concrete structures and to define concrete requirements for a sufficient durability.

Key words: Concrete, hydro-abrasion, simulation, performance tests, aggregate properties.

1. INTRODUCTION

Concrete damage caused by hydro-abrasive exposure is a special topic which is only relevant for certain water exposed structures. International experience on the erosion damage is given in [1] and [2]. In Germany data on abrasion erosion damage of hydraulic structures of the Federal Waterways and Shipping Administration recently has been gathered by an evaluation of the data of the Structural Inspection of the locks and weirs. According to the BAW Code of Practice "Classifying Waterway Construction Damages" [3] the damage is rated on a scale from 1 – 4 (1: good condition, 4: critical condition). Severe abrasion erosion damage (damage rating 3 or 4) was observed on about 10 % of the weirs and 5 % of the locks [4]. The great variety of damage shows Fig. 1.

Figure 1 – Abrasion erosion damage of different degree

2. HYDRO-ABRASIVE EXPOSURE

To design concrete resistance against hydro-abrasive exposure it is essential to know which exposure is expected. Concerning hydro-abrasive exposure not many publications were available [2, 5, 6]. Flow velocity and information on the abrasive load are important parameters to assess the intensity of the exposure as these parameters have a big influence on the abrasion damage [7-10]. As for hydraulic structures like locks or weirs no information was available investigations were conducted by the Technical University of Dresden by order of the BAW [11]. Additional investigations in cooperation with the hydraulic engineers of the BAW were conducted on a severely damaged weir [12]. A Summary of the results was presented in [4, 13]. As a result 3D-hydronumerical-simulations revealed flow velocities with typical ranges on weir sills up to 3.5 m/s, at the stilling basin ground and the ground sill up to 7 m/s respectively 5.5 m/s and up to 6 m/s near strongly damaged baffle blocks. According to [14] these flow velocities are sufficient to move abrasive loads with particle diameters of more than 0.5 m. The abrasive load which was found in structures had diameters up to about 0.3 m.

The period of presence of abrasive material in the structure and its particle size is essential to evaluate the impact intensity. An assessment of the period of presence of abrasive material in the structures currently is not possible as this depends on the flow conditions in the structure and the availability of abrasive material. A classification of the intensity of abrasive impact on concrete structures in the sense of exposure classes presently only seems possible by an assumption of relevant flow velocities and an estimation of the probability of the presence of abrasive load in different parts of a structure.

Furthermore the results concerning the hydro-abrasive exposure of hydraulic structures can be used to evaluate the intensity of laboratory test procedures and their transferability on practical conditions. A summary of the intensity of different laboratory test methods is given in [15]. Comparing the experience of the exposure of hydraulic structures and the intensity of the laboratory tests shows that the tests operate at lower intensity than may be expected under practical conditions.

3. CONCRETE RESISTANCE

For the investigations presented in this paper three test methods were applied in the laboratory of the BAW. Information on the test methods is available in [13]. Fig. 2 shows the test setups. The test procedures operate differently concerning flow velocities, abrasive material (steel balls, gravel) and diameter of the abrasive load. This enables considerations concerning the transferability of test results of different test methods and concerning the transferability to practical conditions at real structures.

Figure 2 – Test setups (ASTM C1138M [16], Bania-method, slab-method)

Differently from other deterioration mechanisms as for example carbonation or chloride ingress where mainly the paste (type of cement, cement content, supplementary cementing materials, water-to-cement ratio) influences the concrete resistance the abrasive attack is a mechanical impact which attacks the whole concrete. Thus the aggregate properties are also important. For that reason for the concrete mix design different aggregates were considered and analysed [13]. The Micro-Deval-coefficient (MD) according to DIN EN 1097-1 [17] seemed a promising parameter as the testing conditions are similar to the hydro-abrasive exposure.

For the mix design the compressive strength was varied in typical ranges covered by the exposure class requirements of DIN EN 206 [18] (C20/25-C35/45). According to DIN 1045-2 [19] the fly ash (72-90 kg/m³) was included in the w/c-ratio with k=0.4. A commercially available blast furnace slag cement CEM III/A 32,5 N LH was used which is a typical type of cement for hydraulic structures in Germany. A cement content of 240 kg/m³ for the C20/25 and cement contents between 285 and 330 kg/m³ for the C35/45 concrete were chosen [13, 15].

The key findings up to now were that the MD-coefficient of the aggregate had a very dominant influence on the concrete resistance [13, 15]. Other aggregate parameters like specific gravity, water absorption or Los-Angeles-coefficient showed no correlation to the concrete resistance against hydro-abrasive impact. At similar strength levels (C20/25) the concrete with the highest MD-coefficient of the aggregate revealed an almost three times higher damage than the concrete with the lowest MD-coefficient of the aggregate. This was observed for all test methods. The ranking of the different concretes was similar for all test methods, too. The compressive strength of the concrete revealed a lower correlation to the abrasive damage than the MD-coefficient. This was still the case when concrete with higher strength (C35/45) was considered [15]. To account for both parameters a new parameter r_{ha} was introduced (equation 1) [15].

$$r_{ha} = \frac{f_c}{MD} \qquad (1)$$

r_{ha} Hydroabrasive resistance parameter
f_c Compressive strength, wet stored cylinder, h/d=2 [MPa]
MD Micro-Deval coefficient, DIN EN 1097-1 [M.-%]

This parameter considers both the influence of the aggregate and the matrix of the concrete which are both affected by the abrasive exposure. Fig. 3 gives an impression of the different abrasion resistance of the matrix and aggregate particles with different properties. The black aggregate grain has remained more or less unaffected by the abrasion exposure during the test whereas the one just below and the matrix have a plain and ground surface.

Figure 3 – Specimen detail after abrasion test

Further investigations and evaluations are necessary to define appropriate requirements for concrete exposed to hydro-abrasive exposure.

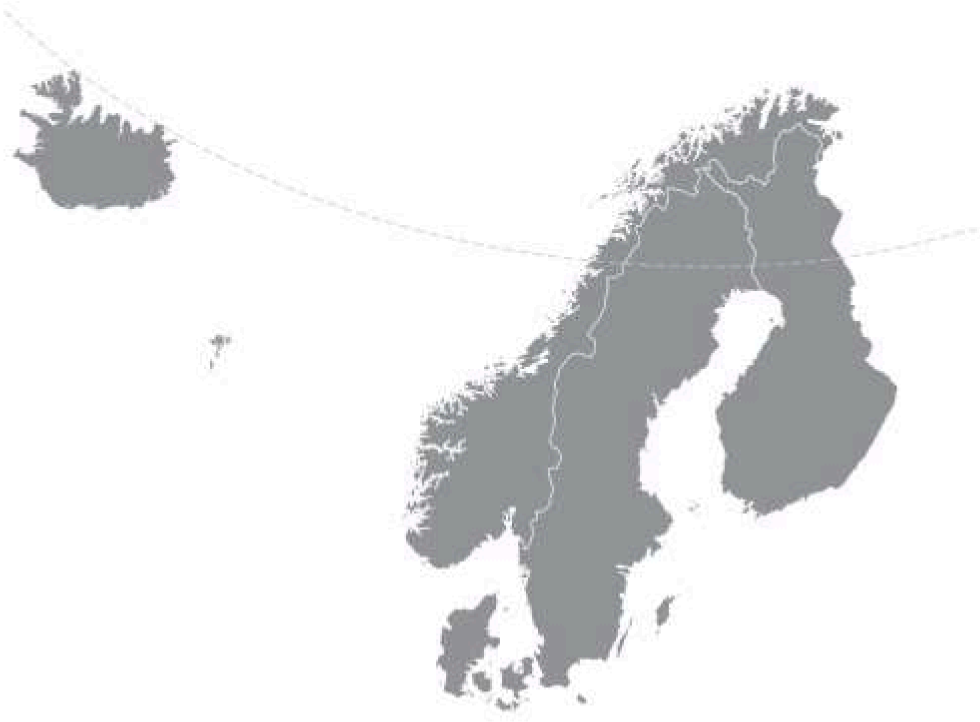
REFERENCES

1. Tatro S. B. et. al., “Compendium of Case Histories on Repair of Erosion-Damaged Concrete in Hydraulic Structures”, *ACI 210.1 R-94* (Reapproved 1999).
2. Jacobs, F.; Winkler, K.; Hunkeler, F.; Volkart, P.: “Betonabrasion im Wasserbau – Grundlagen – Feldversuche – Empfehlungen.“, *Mitteilungen der VAW der ETH Zürich*, No. 168, 2001 (In German)
3. BAW Code of Practice “Classifying Waterway Construction Damages”, Karlsruhe, Federal Waterways Engineering and Research Institute, 2018 (In German)
4. Spörel, F.; Helbig, U.; Westendarp, A.; Stamm, J.: „Hydroabrasionsbeanspruchung von Verkehrswasserbauwerken“, *Bautechnik*, Vol. 92, No. 8, August 2015, pp. 538-548 (In German)
5. Kryžanowski, A. et al.: „Testing of Concrete Abrasion resistance in Hydraulic Structures on the Lower Sava River.” Strojniški vestnik - *Journal of Mechanical Engineering*, Vol. 58, No. 4, 2012, pp. 245-254.
6. Hagmann, M.; Albayrak, I.; Boes, R. M.: „Field Research: Invert Material Resistance and Sediment Transport Measurements”, *Mitteilungen der VAW der ETH Zürich*, No. 232, 2015, pp. 123-135
7. Bania, A.: “Bestimmung des Abriebs und der Erosion von Betonen mittels eines Gesteinsstoff-Wassergemisches“, phd-thesis, TH Wismar, Germany, 1989 (In German).
8. Haroske, G.: „Beitrag zum Hydroabrasionsverschleiß von Betonoberflächen“, *phd-thesis*, Universität Rostock, Germany, 1998 (In German)
9. Horszczaruk, E.: Mathematical model of abrasive wear of high performance concrete, *Wear* 264, pp. 113-118, 2008
10. Vogel M.: “Schädigungsmodell für die Hydroabrasionsbeanspruchung zur probabilistischen Lebensdauerprognose von Betonoberflächen im Wasserbau“, *phd-thesis*, Karlsruher Institut für Technologie, Germany, 2011 (In German)
11. Stamm, J.; Helbig, U.: „Wissenschaftliche Bearbeitung der Einwirkseite hydroabrasiver Belastungen auf Wasserbauwerke" – *research report* 2014/14, Technische Universität Dresden, 2016 (in German)
12. Siggelkow, M.: „Hydroabrasion an Wehranlagen - Hydronumerische Simulation zum Verständnis der Schädigungsmechanismen.“ *Master thesis*, Karlsruhe University of applied science, 2016 (in German)
13. Spörel, F.: Hydroabrasive exposure and concrete resistance against abrasion erosion. ACI SP-326 Durability and Sustainability of Concrete Structures (DSCS 2018) - *Proceedings 2nd International Workshop*, pp. 75.1-75.10, 2018
14. ACI Committee 210: “Erosion of Concrete in Hydraulic Structures”, ACI 210R-87. ACI Materials Journal, 84-M17, 1987, pp. 136–157
15. Spörel, F.: Influence of concrete properties on the resistance against hydroabrasive impact. *Proceedings* fib Symposium 2019 Concrete-innovations in materials, design and structures. Krakow, 2019
16. ASTM C1138M-05 (Reapproved 2010): “Standard Test Method for Abrasion Resistance of Concrete (Underwater Method).”, *ASTM International*, 2010
17. DIN EN 1097-1:2011-04 “Tests for mechanical and physical properties of aggregates - Part 1: Determination of the resistance to wear (micro-Deval)”
18. DIN EN 206-1:2001-07 “Concrete - Part 1: Specification, performance, production and conformity”
19. DIN 1045-2:2008-08 “Concrete, reinforced and prestressed concrete structures - Part 2: Concrete - Specification, properties, production and conformity - Application rules for DIN EN 206-1”

Concrete in arctic conditions

WORKSHOP PROCEEDINGS FROM A NORDIC WORKSHOP

Trondheim – Norway, 18–19 June 2019



Nordic Concrete Federation

ISBN: 978-82-8208-067-5 **ISSN 0800-6377**

A list of previous and upcoming Nordic workshops is available on www.nordicconcrete.net

Printed (made) by: NTNU Grafisk senter